Economic growth, employment and energy

Chauncey Starr and Stanford Field

The importance of energy in achieving economic growth emerged as an issue in the USA at the end of the 1960s, when readily usable domestic supplies of inexpensive oil and natural gas began to dwindle. Because of this, energy considerations may, for the first time, begin to constrain society's freedom to explore future options for continued economic and social progress. Prudent planning requires that the US energy supply goal should be high enough to avoid energy constraints. This article estimates how much energy will be needed in the year 2000 for the USA to achieve social progress, unconstrained by energy availability. These estimates are based on examination of the interactions between economic growth, employment, and energy use. The USA may choose not to follow the historical trend of economic growth. If so, the authors feel that this should be a decision, reached on the basis of broad national economic policy, and should not be an unintended and unrecognized side-effect of energy policy.

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As one looks back at the first three-quarters of the 20th century, one cannot fail to be awed by the progress which has been made in the USA. In the so-called 'Gay Nineties' men worked harder and longer for less pay, as shown in Table 1 and the average housewife laboured endlessly, caring for her husband and four children. Child labour was encouraged by industry and agreed to by parents. In 1900 there were about 1.75 million child labourers in factories,[1] and thousands more working in the cities as vendors, messengers or shoeshine boys. In some factories eight was the minimum age for employment. In Massachusetts, one of the most progressive states, the working day of children under 12 was legally confined to 10 hours.

Conditions have since changed, but we still wish to continue the steady improvement of social welfare maintained in the past. An important contributor to this progress has been the steady increase in economic productivity which, in turn, has been mainly driven by technical advances in energy-using capital equipment.

The importance of energy in achieving economic growth emerged as a national issue at the end of the 1960s when readily usable domestic supplies of inexpensive oil and natural gas, accounting for about 80% of energy used in the USA, began to dwindle. Pronouncements of impending shortages of oil and gas gave rise to the popular belief that a world energy shortage was imminent. More recently, recognizing an opportunity, OPEC quadrupled oil prices within a year.

A necessary basis for steady improvement of social well-being, as measured by levels of employment, health, education, housing, medical care, and other amenities is the continuation of gains in economic productivity. Because of the direct relationship between productivity and energy use, a main premise is that social and economic structures could be substantially and regressively altered by large energy use constraints. These could result either from limited supplies of conventional energy resources or from very high energy costs. Because of the past abundance of low-cost energy, the historical rate of social progress was not limited by energy considerations, but was determined principally by other conditions.

To maintain society's freedom to explore future options for continued economic progress the energy supply target should be large enough to avoid energy constraints. These constraints can occur because market imperfections, caused for example by controlled

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Table 1. Historical comparison of salary and energy use in the USA (average full-time employee)

	1900	1973
Average hours worked per week	53	39
Average hourly wage (1975 $)	0.82	4.93
Average annual salary (1975 $)	2 300	10 000
Average energy use (million Btu/year/employee)	356	885

energy prices, do not allow supply and demand to reach equilibrium. Because the development of feasible technical options must be undertaken decades ahead of the expected need, the time span to the year 2000 has been chosen for analysis. The quantitative estimates of needs for economic growth, employment, and energy in the year 2000 are intended as planning targets to avoid energy-constrained societal progress and are not meant as forecasts for the future. If the USA is to choose a path differing from the historical trend, this should be a decision reached on the basis of broad national economic policy and not as an unintended and unrevealed side-effect of energy policy.

The energy-productivity system

The basic industrial system of any country (Figure 1) uses domestic and foreign resources of capital (K), labour (L), energy (E) and materials (M) to satisfy a demand for an annual flow of goods and services. These inputs are supplemented with technical knowledge which may be defined as all scientific, engineering and other know-how used in the production process.

The various inputs are mixed together in a myriad of industrial activities and are transformed into outputs. The market value of these outputs of goods and services, produced in a given time, form the gross domestic product (GDP).

[1] Otto L. Bettmann, *The Good Old Days – They Were Terrible*, Random House, New York, 1974.

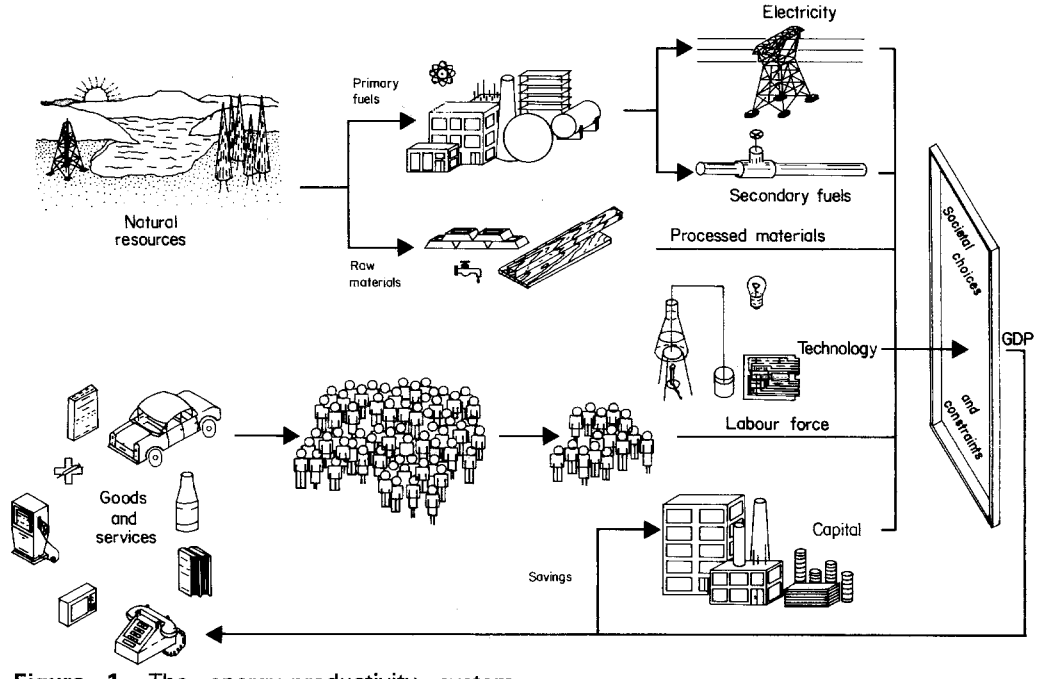

Figure 1. The energy-productivity system

When income earned from foreign investments is added to GDP, the sum is gross national product (GNP). These goods and services are available to satisfy the demands of consumers, investors, government and foreign countries. Much of what is produced is consumed by the domestic population, although many countries export substantial amounts of their production.

In developed economies, a significant portion of the GNP may be allocated as 'savings' and re-invested in the system to replace and augment existing capital stock (machinery, factories, buildings, stores of finished and unfinished materials) and thus contribute to economic growth. Savings for capital formation occur primarily from depreciation and corporate and personal savings.

Decisions to invest or form capital are primarily based on an expected stream of returns over time. Policies that influence savings and investment decisions also directly affect capital formation. Historically, additions to capital stock combined with improving technology have helped to increase economic productivity and real incomes.

The energy-productivity system is in a state of perpetually changing activity. A major driving force of the system in any country is the continuous growth of the population and its labour force which requires the continuous creation of new employment opportunities.

The creation of stable, productive employment opportunities is dependent upon the state of all the input forces of the system:

- the availability of capital for new production facilities;
- the mental and physical capacity of the labour force;
- the availability of economically usable primary energy, raw materials, and conversion facilities; and
- the availability of technology.

At the same time, employment opportunities depend also on the effective demand for goods and services.

The rich endowment of natural resources in the USA and the invention of technology to use those resources allowed the development of an economic system which tended to be self-sufficient and minimized dependence on foreign trade. Because of the past abundance of low-cost energy, decisions made in our freely motivated economic system have evolved into the current patterns of energy use in transportation, housing, commercial buildings and industrial processing facilities. The relatively low cost of energy tended to increase its use and tended to limit the use of capital in conserving energy. This increased the availability of capital for other uses.

We are here principally concerned with the factor inputs of labour and energy. Although capital and materials are also essential to economic activity, their inputs have not been explicitly examined. However, implicit in this analysis has been the substitution of capital and materials to effect energy conservation.

Economic growth and employment

The continuous growth of the US population and its labour force has required the corresponding continuous creation of new jobs. Employment has been a primary goal and planning objective of American society. This is exemplified in the Employment Act of 1946

Table 2. US population and labour force (millions)

	1950	1975	2000
Total population	152	214	263
Labour force	62	93	118
Employed civilians			
Men	42	52	65
Women	17	33	48
Total	59	85	113

Sources: Refs 3 and 4.

which states that it is '... the continuing policy and responsibility of the federal government ... to coordinate and utilize all its plans, functions, and resources ... to promote maximum employment, production, and purchasing power.'

After estimating expected fertility and death rates, one may project a population of 263 million people for the year 2000.[2] The corresponding civilian labour force is estimated to be 118 million. To place these figures in perspective, a look at the last 25 years and a projection for the next 25 years is shown in Table 2.

Although the civilian employment growth rate is expected to slow modestly from 1.5% per year (1950-1975) to about 1.2% per year in the next quarter century (1975-2000), the number of additional people requiring employment will increase from 26 million (1950-1975) to 28 million (1975-2000). The trend for women to increase their participation as workers is evident from Table 2. In 1950, about 29% of workers were women. By the year 2000 the women's share of the labour market may increase to 42%.

The growth of the civilian labour force demands related increases in economic growth (GDP) to create jobs and to maintain full employment. In the USA, the level of economic activity, as measured by GDP, is dependent upon

- the size of the employed labour force,
- its annual hours of work, and
- its productivity or ability to produce marketable goods and services.

The following identity describes the relationship:

$$\text{GDP} \equiv L \cdot H \cdot P$$

where GDP = dollars per year, L = number of people employed, H = average hours worked per year by an employee, P = productivity in dollars per hour per employee.

A review of the 83 years from 1890 to 1973 shows the real output of goods[3,4] and services in 1973 was *nearly 16 times* what it was in 1890, and was achieved *with only four times as many workers*, as shown by the increasing curvature in Figure 2. After accounting for a reduction in the average workweek[5] from 54 hours in 1890 ($5\frac{1}{2}$ ten hour days) to about 40 hours in 1973, one can calculate that the spectacular rise in the GDP per employee was due to a five-fold increase in productivity.

The relationship between GDP and employment for the USA over the past 85 years is approximated by the equation:

$$\text{GDP} = 156 \quad e^{0.0235L} - 252$$

[2] US Department of Commerce, Bureau of the Census, *Projections of the Population of the US, by age and sex, 1975 to 2000*, US Government Printing Office, Washington, DC, 1975.

[3] US Department of Commerce, Bureau of the Census, *Historical Statistics of the United States, Colonial Times to 1970*, Bicentennial Edition, US Government Printing Office, Washington, DC, 1975.

[4] US Department of Commerce, Bureau of the Census, *The US Fact Book, The Statistical Abstract of the US 1976*, Grosset and Dunlap, New York, 1976.

[5] US Bureau of Economic Analysis, *Long Term Economic Growth 1860-1970*, US Government Printing Office, Washington, DC, 1973.

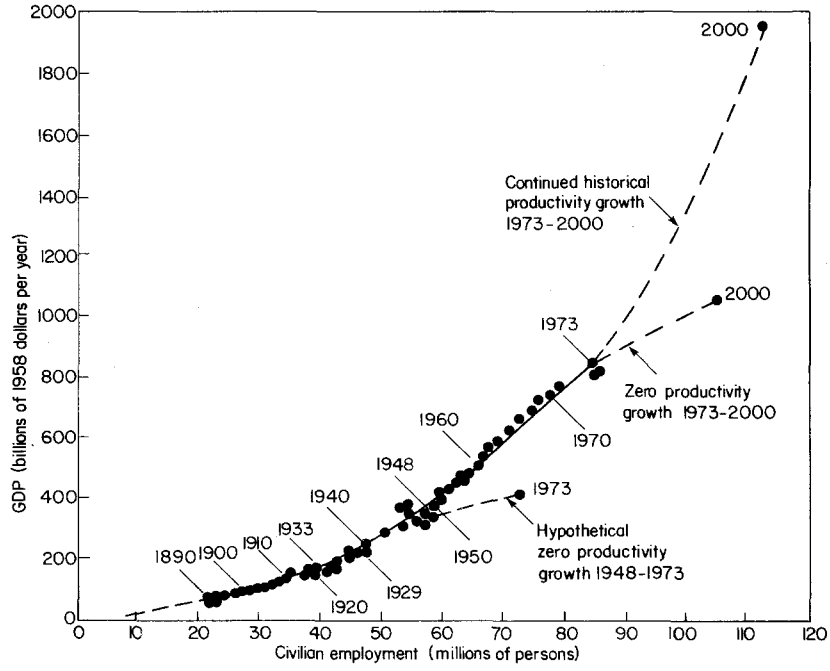

Figure 2. Employment and GDP in the USA

where GDP is in billions (10^9) of 1958 dollars per year and L is in millions. Assuming that this relationship properly describes a continuing normal trend, an estimate of the employment level at any future time should provide an estimate of the GDP associated with that employment. This equation assumes the same tendency of structural change that has manifested itself historically and therefore serves as a reference base. If $L = 113\,000\,000$ in 2000 then, with a 4% unemployment rate and historical trends in productivity and hours worked, GDP would be \$1970 billion/year (1958\$). This GDP figure is subsequently used as the level of economic activity that represents a continuation of the historical trend to the year 2000.

As an extreme contrast to this first case, which assumes a continuation of the historical trend, a hypothetical 'no productivity growth' second case was considered which assumes a freeze of GDP per employee (constant productivity and workweek) at the 1973 value; under these conditions, GDP in the year 2000 would be only \$1050 billion 1958 dollars per year. Because the 1973 GDP is the integrated effect of old and new productivity patterns and lifestyles existing in 1973, freezing the GDP/L ratio at the 1973 level can be assumed to correspond to freezing all major social and industrial patterns.

A summary of major US economic variables for the period 1890-1948 and for the postwar era, 1948-1973, as well as a view to the year 2000 is shown in Tables 3 and 4 and a century of trends for employment, workweek, and productivity are shown in Figures 3, 4, and 5. These illustrate the magnitude of the changes.

Productivity is the major variable which reflects the evolutionary character of economic development, as mental and physical skills are applied to increase economic output. A number of factors have contributed to the steady exponential growth of productivity. Foremost among these is technical innovation which permitted the substitution of mechanical power for human labour. The continuous

Table 3. Major US economic variables

	1890	1948	1973	2000 Historical growth	2000 No productivity growth
GDP (billion 1958 $/year)	53	324	839	1 970	1 050
Employment (million persons)	22	58	84	113	106[a]
Workweek (hours/week)	54	43	39	36	39
Productivity (1958 $/h/employee	0.87	2.49	4.89	9.45	4.89

[a]Assumes the 1973 ratio of men to women employees and a 1973 participation rate for males of 16-64 years of age.

Table 4. Growth rates of major economic variables in the USA (percent per year)

	1890-1948	1948-1973	1973-2000 Historical growth	1973-2000 No productivity growth
Employment	1.7	1.5	1.1	1.1
Workweek	−0.4	−0.4	−0.4	zero
Productivity	1.8	2.8	2.5	zero
GDP	3.1	3.9	3.2	1.1

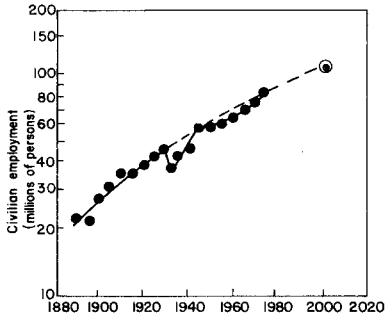

Figure 3. Civilian employment in the USA

advances of the scientific world were integrated synergistically to form highly productive systems. Expert management of these systems, which capitalized on the concepts of standardization, mass production, economies of scale, and the speed of information processing, served to expand productivity.

For the future, it seems reasonable to expect continued advances in the growth of productivity resulting from technological progress and its implementation, improvements in the management of capital labour, energy, and materials, and increases in the educational level of employees.

US energy planning target for the year 2000

The root of all energy projections for the USA is a judgment as to the probable level of output of goods and services of a future US economy. This is the quantitative corollary of a perceived future national level of economic welfare and development.

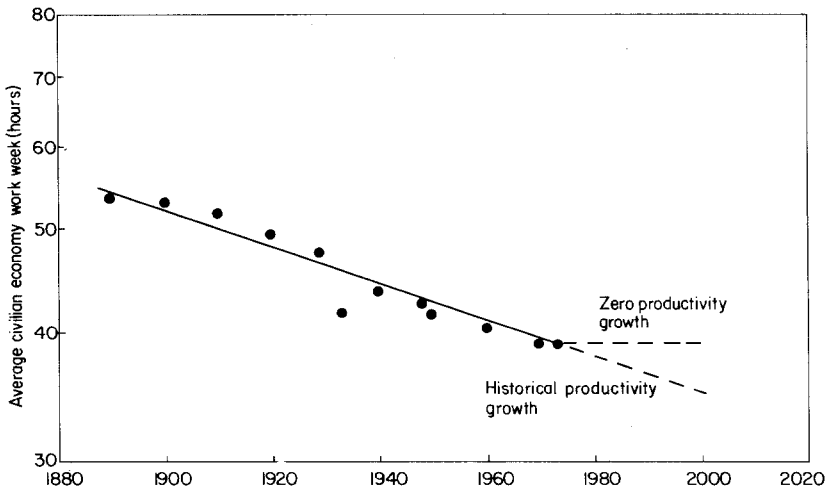

Figure 4. Average work week in the USA

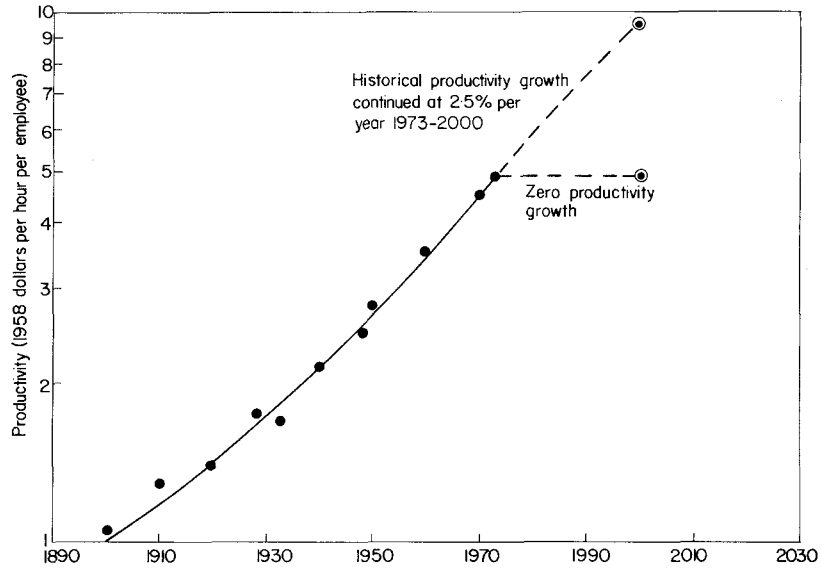

Figure 5. Productivity growth in the USA

Once a target is set for GDP, the energy needs of the nation can be roughly estimated. For the period 1890-1975, total primary energy consumption [3,4] tends to follow GDP (Figure 6) with a linear relationship described by the equation:

$$E = 5 + 0.0833\,\mathrm{GDP}$$

where E is total primary energy use in 10^{15} Btu/year (quads/year) and GDP is gross domestic product in billions of 1958 $/year.

The relationship reflects the elemental fact that the combination of capital equipment, labour, energy (fuel and solar), and raw materials creates our goods and services. Fuel energy is a primary input essential to all sectors of the economy; even food production is heavily dependent on a fuel energy input, in addition to that supplied by solar energy. Economic output and energy are thus linked,

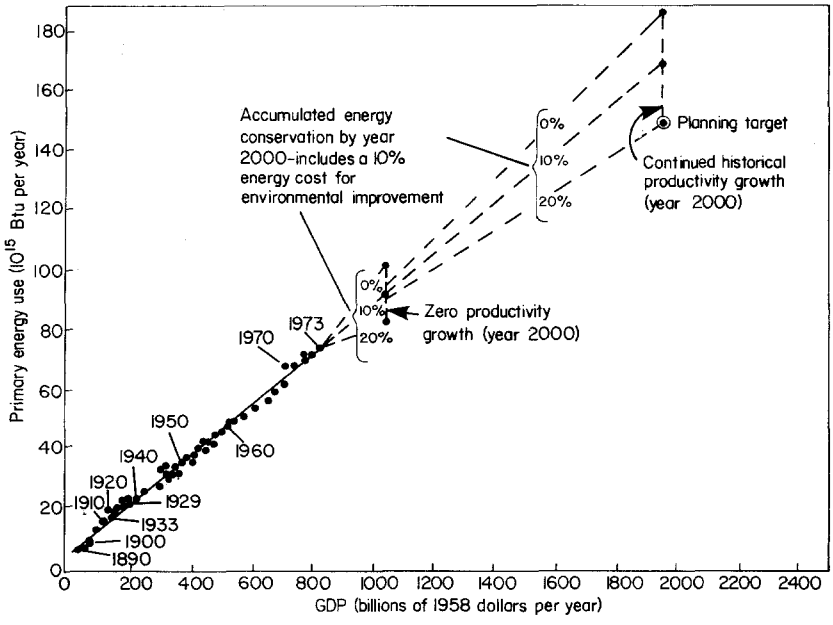

Figure 6. GDP and primary energy use in the USA

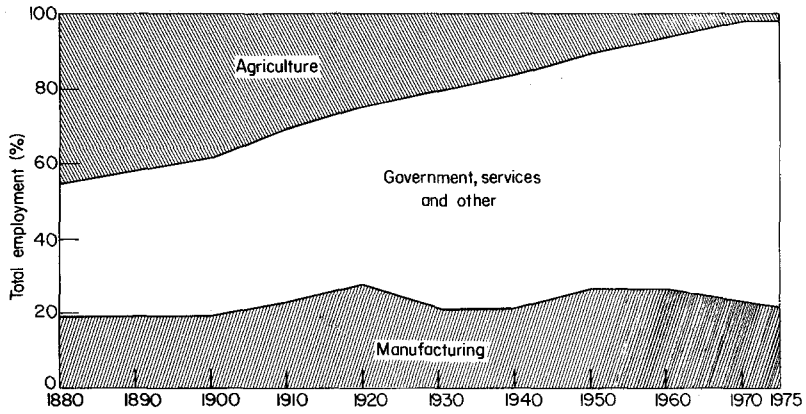

Figure 7. Occupational distribution of employed civilians in the USA

Table 5. US occupational distribution (percentage of total employment)

	1880	1975
Agriculture	51	4
Manufacturing	19	21
Government	1	18
Services	11	17
Other[a]	18	40

[a]Includes such categories as wholesale and retail trade, finance, insurance, real estate, contract construction, transportation, public utilities, and mining.

although the relationship depends on how well primary energy is used to produce an economic end product. The reversible relationship of GDP and energy is demonstrated by the sharp drop in GDP of 30% between 1929 and 1933. This was caused by economic changes unrelated to energy availability and was accompanied by a similar decline in energy use. From 1933 to 1940, as the USA climbed out of the Great Depression, GDP rose 60% and the energy input correspondingly rose by 50%. The relatively close linkage of GDP and energy use has been again demonstrated by the data for the last few years.

For the last century the occupational mix[3,4] of the USA has slowly and steadily shifted from that of an agrarian economy to one which is oriented to government, services and other nonagricultural activities as illustrated in Figure 7 and in Table 5.

Despite these large shifts in occupational distribution over nearly a century, the linear relationship between GDP and primary energy use was not significantly altered.

Another fundamental association is that of annual total primary energy use and employment[6] as shown in Figure 8. The historical relationship, which has held for 75 years, is:

$$E = 13e^{0.0235L} - 16$$

where E = total primary energy in 10^{15} Btu per year and L = employed civilians in millions.

The continuing curvature shown in Figure 8 is the result of the combined effects of a continuous annual increase in productivity which has more than offset the continuous decline in the annual hours worked.

On the assumption that this relationship, with its implied trends in productivity and hours worked, properly describes a continuing normal trend, an estimate of the employment level at any future time should provide an estimate of the total primary energy associated with that employment. This estimate serves as a reference base for consideration of future changes in the structure of energy use and employment. In effect, the above equation relating energy and employment assumes the same tendency for structural change in the future that has manifested itself historically. The equation predicts that the expected employment level of 113 million in the year 2000 will require an energy input of 170 x 10^{15} Btu. However, the structure of the

[6] S. Field, *The 1975 US Energy Puzzle*, San Francisco, 1976.

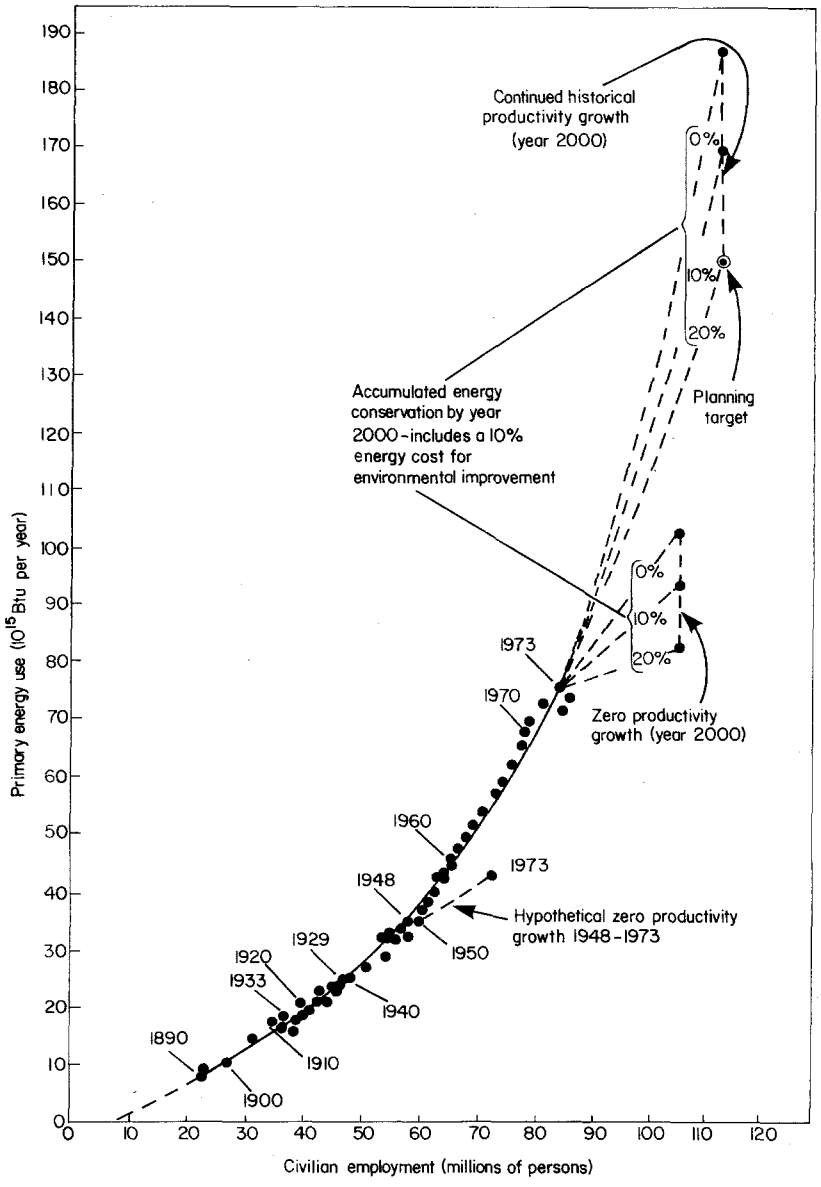

Figure 8. Employment and primary energy use in the USA

relationship may be changed by intensive energy conservation and energy costs associated with environmental improvement.

Projections of energy relationships with both GDP and employment have been modified to account for the energy costs of meeting anticipated social goals of improving the environment through a reduction in pollution, and of energy conservation resulting mainly from significantly higher energy prices in the next quarter century. These two effects are not included in the historical data, and as a result, adjustments for them must be estimated independently.

Environmental energy effects

The achievement of an improved environment through a reduction of pollutant emissions, reduction of ecological impacts, and changes in the urban–rural population distribution is often accompanied by inefficiencies in the use of fuel and capital resources. Although the social benefits of environmental improvement should justify such

additional costs, it is important to recognize that we must expect to pay such costs, and that our estimates of future demands on resources should take them into account.

Consider, for example, the decrease in conversion efficiency of a conventional electric power station when changing from water-cooled to air-cooled condensers – as part of a programme to reduce the ecological effects on water resources. Due to the higher temperature of the steam cycle condenser with air cooling, the fuel consumption is increased by about 6-10% for fossil fuel plants and by 7-13% for nuclear plants; the related increase in capital investment per unit output is about 10-15% due to the higher cost of the air-cooled condenser system.

Another example is the removal of undesirable chemicals from coal prior to combustion. At present, all precombustion systems for conversion of coal to purified gases or liquids require heat – ranging from 20% to 50% of the heat content of the input coal, depending on the process. Flue gas purification, required after the direct combustion of high sulphur fuels, takes 5-10% of the input heat. Purification during combustion by a fluidized bed boiler may use only about 2% of the input energy, but this is the least developed approach and probably will not be commercially available for several decades. All of these methods add substantial increments to the energy and capital costs of the electric power systems.

Most other environmental requirements for energy systems increase the amount of fuel and capital required to provide the same end-use function. Consider, for example, the increased fuel consumption of motor vehicles which is associated with pollution restrictions. To meet increasingly stringent standards, which limit emissions of nitrogen oxides, carbon monoxide and unburned hydrocarbons, car manufacturers were forced toward lower compression ratio engines (less efficient), the recycling of exhaust gases to the combustion chamber and the use of catalytic converters. To achieve the stringent standards for emissions, it would have been necessary to give up about 25% of the mileage per gallon based on pre-1970 engine designs. To offset such a drastic loss in fuel economy, car manufacturers have had to substitute capital for energy use by installing, for example, electronic fuel injection to improve combustion.

Counterbalancing these decreases in efficiency of resource use is the constant trend of technical improvements which provide the same end-use with less input. Clearly, it is impractical to gauge the effect of unknown future technologies but improvements can be expected. Based on present environmental objectives, it is reasonable to expect that total energy requirements for meeting these objectives will increase by about half a percent per year during the next quarter century to reach 10-15% of energy needs in the year 2000. A planning target of a 10% increase over the historical trend has been used. Quantitatively, this amounts to 17×10^{15} Btu per year by the year 2000 or the equivalent of nearly all the oil-derived fuels used for transportation (cars, lorries, buses, trains, aeroplanes etc) in the USA in 1976.

Energy conservation

A reduction in energy requirements for the nation may be achieved

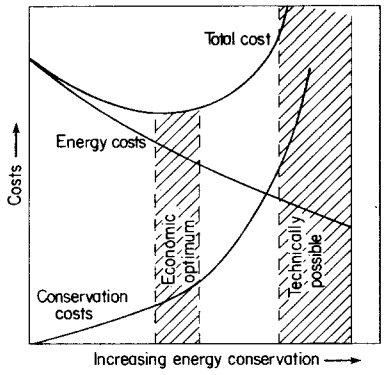

Figure 9. Energy and conservation costs *v* level of conservation.

both by increasing the efficiency with which primary energy is used and also by changing national lifestyles.

Energy conservation may be induced as a result of

- economic penalties incurred by rising energy costs relative to an average of all other items;
- legislative action;
- voluntary public actions.

Of these three types, the most important is probably price-induced energy conservation which will affect all sectors of the economy. This type of energy conservation (reduction in energy waste) results principally from attempts to minimize total cost by trading capital investment to conserve fuel with the cost of additional fuel, as shown in Figure 9. Energy waste may be defined as that energy, which, if saved, would either hold constant or reduce the cost of a product, reflecting optimal use of capital, labour, energy and materials, or hold constant or reduce costs without changing comfort.

For any specific use of energy the incremental cost of conservation increases as the degree of conservation increases. A simple explanation of this is that the conservation methods which are more cost effective are the first to be implemented. For example, the homeowner who wishes to reduce the consumption of energy for home heating usually begins with the installation of ceiling insulation, and perhaps some leak plugging through the use of weather stripping. If further improvement is desired, the walls can be insulated and double glazing installed. These last two steps are much more expensive, in general, than the first two, yet more fuel is saved by the first two methods. Thus, optimal energy conservation taking into account the use of all resources (capital, labour, energy and materials) will always be substantially less than what is technically possible.

Short term action must be limited in its effects because of the existence of houses, commercial buildings, industrial plants and vehicles, that have been built based on the economics of inexpensive energy. As new energy conservation oriented units are constructed, manufactured and placed into operation a gradual accumulation of energy conservation will occur. For example, if all new US housing to the year 2000 (about 42 million units) were constructed to give 30% energy savings relative to the 71 million pre-1976 houses, the combined effect would yield only 11% energy savings in the residential sector by the year 2000. However, the retirement of old housing and replacement with new energy efficient stock would tend to increase the overall conservation to perhaps 15%.

Similarly in the case of industrial facilities, existing plants cannot be scrapped because of the great amount of capital already invested. Facilities will instead be allowed to wear out and only then replaced with plants designed to save energy. This slow process of replacing industrial capital stock will mean only a gradual accumulation of energy conservation.

In the transportation sector, energy savings may occur more rapidly because the current stock of about 140 million motor vehicles is being retired at a rate of about 7 million per year. By the year 2000 an entirely different stock of vehicles should be on the road. Recent legislative action requires car manufacturers to produce passenger cars in 1985 that average 27.5 miles per gallon compared to an average of perhaps 12-14 miles per gallon in 1976. Another example

Table 6. US energy conservation potential in various sectors

Sector	Sector importance (sector consumption as % of total energy consumption) 1973	2000 (unperturbed)	Potential energy savings (% of year 2000 sector energy demand)	Weighted potential annual savings (% of year 2000 unperturbed total energy demand)
Residential and commercial	36	40	15	6
Industrial	39	40	15	6
Transportation	25	20	40	8

of legislative energy conservation occurred during the oil embargo of 1973-74 when the speed limit was reduced to 55 miles per hour throughout the nation. These, and similar actions in the future, may result in accumulated energy savings of about 40% in the transportation sector by the year 2000.

The optimal level of conservation, in terms of cost, is not known, and estimates vary widely. Most estimates of the lowest cost point involve conserving 20-40% of the fuel which would be used up to the year 2000 if present trends continued. Given the imperfections of the market, the uncertainties, and the institutional barriers to capital investment for energy conservation, 20% conservation is a reasonable planning target.

The expectations for reasonable energy conservation are summarized in Table 6. No attempt has been made to allocate energy costs for environmental improvement in each sector. As a planning goal, total energy demand in the year 2000, including environmental improvement energy costs, of 187×10^{15} Btu/year may reasonably be expected to be reduced by 37×10^{15} Btu or the equivalent of nearly 50% of all the energy used in the USA in 1976.

To summarize, a reasonable expectation for energy costs associated with environmental improvement is estimated to be about 10% greater energy use by the year 2000 or about 17×10^{15} Btu/year; energy conservation is expected to reduce total primary energy needs including environmental energy costs by about 20% or about 37×10^{15} Btu/year.

The year 2000 energy planning target, based on historical productivity growth, unconstrained by energy availability, is summarized in Table 7.

Two principal findings from the preceding analysis can now be stated:

- The demand for primary energy is directly related to the level of

Table 7. US primary energy needs in the year 2000 for continued historical productivity growth (10^{15} Btu/year)

	Energy conservation Zero	10%	20%
Unperturbed trend	170	170	170
Environmental costs	+ 17	+ 17	+ 17
Conservation	zero	− 19	− 37
Total primary energy requirement	187	168	150

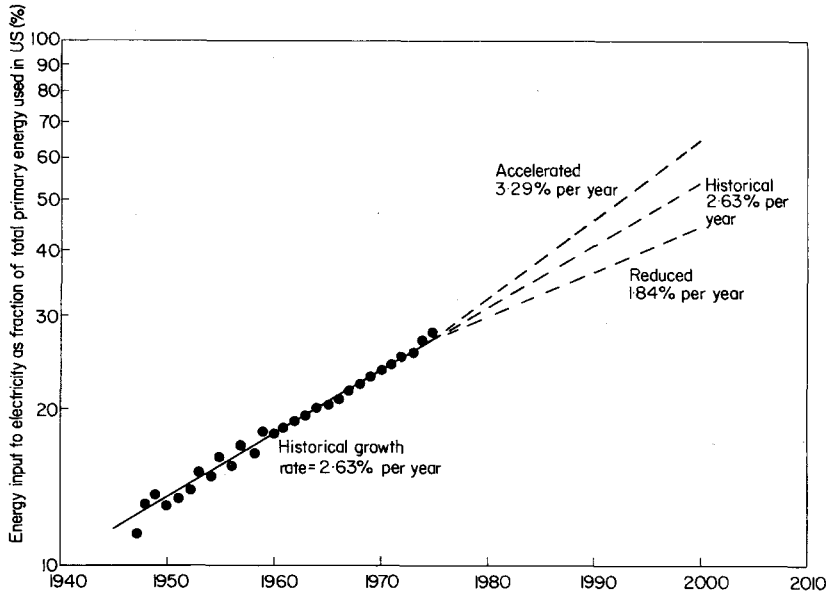

Figure 10. Relationship between electricity consumption and total primary energy consumption in the USA

employment, the time worked, and the average output per employee.

- For growth in economic productivity to continue at the historical rate, unconstrained by energy availability, the total primary energy requirement for the USA is estimated to be *150×10^{15} Btu per year* by the year 2000 (1973-2000 growth rate of 2.6% per year). This includes reasonable allowances for energy conservation and energy costs associated with environmental improvement.

US electricity planning target for the year 2000

US energy requirements for the year 2000, based on unperturbed continuation of the historical trend, are estimated at 170×10^{15} Btu per year. Electricity demand can be estimated by projecting the probable fraction of total energy that is likely to be required in the form of electricity. Adjustments can then be made to allow for conservation and for energy costs associated with environmental improvement.

From 1960 to 1973 the fraction of total primary energy input used to generate electricity grew at an annual rate of 2.63%, as shown in Figure 10. Extrapolation to the year 2000 indicates that 53% of all primary energy will be used as fuel for the generation of electricity. This appears reasonable, although it is not evident how much of the past growth was cost motivated and how much was due to the utility value attached by consumers to such characteristics of electricity as convenience and uniqueness of application. While it is recognized that the growth rate of electricity's share must eventually decrease, due to saturation, the slowing is not assumed to occur before the year 2000.

The factors that will eventually affect the amount of energy delivered as electricity are:

- total primary energy use;
- accelerated or reduced electricity use due to interfuel substitution; and

Table 8. Potential electricity savings for the USA

Sector	Sector importance in year 2000 (% of total electricity consumption)	Potential savings (% of sector electricity use in year 2000)	Weighted potential savings (% of total electricity use)
Residential and commercial	50	20-40	10-20
Industry	40	15-30	6-12
Transportation	10	10-20	1-2
Total			17-34

- reduction in electricity use due to conservation, which includes end-use efficiency improvements, life-style changes and price induced falls in demand.

The rate of substitution of electricity for other energy forms could be altered by a number of factors. The most important is the unreliability of future supplies of oil and gas. Even today, the threat of future shortages of natural gas has resulted in the choice of electric heat for much new construction. Technological developments requiring the use of electricity, such as the electric car, will also tend to increase the electric fraction. Owing to uncertainties about the future we assign a range of values to the 'electrification' – the percentage of total primary energy input going to electricity generation. On the historical growth assumption the percentage in the year 2000 is estimated at 53 ± 10.

The conservation potential for electricity use[7] is expected to be less than the national average for all energy because most electricity consuming devices are already of high efficiency. A 17% reduction in electricity requirements attributable to conservation has been estimated as a reasonable target. While a 34% reduction is technically possible, this has been labelled an extreme case because it implies the universal adoption of, and capital investment in, every possible energy saving measure – which is highly unlikely. The potential electricity conservation by consuming sector is shown in Table 8.

The electricity planning target can now be estimated by taking 53% of the total primary energy demand for the year 2000 of 170 x 10^{15} Btu/year (continued historical growth unadjusted for energy conservation or environmental improvement energy costs). This gives a primary energy input to electricity generation of 90 x 10^{15} Btu/year. Conservation in electricity use of 17% reduces the 90 x 10^{15} Btu/year to 75 x 10^{15} Btu/year. The production of electricity corresponding to this fuel supply can be calculated using an estimate of the year 2000 conversion efficiency. This efficiency (heat rate) presently averages about 10 500 Btu/kWh. Extrapolation of recent heat rate trends gives 10 000 Btu/kWh for the year 2000, which reflects the continuing albeit slow improvement in average conversion efficiency. At this heat rate, roughly 7 500 billion (10^9) kWh of electricity would be required. By varying the electric fraction ± 10% (43% to 63%) and by varying the conservation estimate the matrix shown in Table 9 has been calculated.

Thus a combination of the historical rate of electrification and a reasonable level of electricity conservation would lead, very probably, to a year 2000 electricity demand[8] of about *7 500 billion kWh* which

[7] Craig B. Smith, ed, *Efficient Electricity Use: A Handbook for an Energy Constrained World*, Pergamon Press, New York, 1976.

[8] Chauncey Starr, 'Electricity Needs to the Year 2000 as Related to Employment, Income, and Conservation', presented to the Subcommittee on Energy Research, Development, and Demonstration, House Committee on Science and Technology, Washington, DC, 26 February 1976.

Table 9. US electricity demand in the year 2000 on the basis of continued historical productivity growth (billion kWh per year)

Level of electricity conservation		Electric fraction 43% (Reduced growth)	53% (Historical growth)	63% (Accelerated growth)
None	0%	7 300	9 000	10 700
Reasonable	17%	6 070	7 500[a]	8 900
Extreme	34%	4 820	5 950	7 070

[a]7 500 billion kWh/year has been chosen as the year 2000 planning target for continued historical productivity growth.

is 3.9 times the 1975 level of 1 916 billion kWh. To meet the year 2000 electricity needs, permitting continued historical growth of economic productivity, prudent planning should accommodate an average electricity growth of 5.6% per year.

The energy costs for environmental improvement in electricity generation are expected to increase the heat rate by 10% to 11 000 Btu/kWh in 2000. Thus, a total primary energy input of 82.2 x 10^{15} Btu/year will be required to generate the planning target requirements of 7 500 billion kWh/year. To supply this primary energy input, the USA must concentrate on the adequate indigenous fuel resources of coal and uranium. Most oil and gas is expected to be reserved for non-substitutable uses such as automotive and air transportation, petrochemicals, and requirements for existing gas and oil-fired homes and commercial buildings. To the extent that energy may be obtained from additional hydroelectric and geothermal sources and new solar thermal stations, these sources will be welcome additions to reduce the requirements of the workhorses – coal and uranium.

Oil and natural gas imports

The use of indigenous coal and uranium resources as electricity to meet most of the required growth in total energy demand can substantially reduce oil and natural gas imports as shown in Table 10.

The above calculations assume that oil and gas for electricity generation will be limited to 5 x 10^{15} Btu in the year 2000 and that domestic production of oil and gas in the year 2000 will be the same as current levels. It becomes evident that increasing electrification, using coal and uranium, leads to important reductions in the need for foreign oil and gas. In fact, Table 10 suggests that with 65% of total energy being converted to electricity (8 900 billion kWh/year) oil and gas imports can be reduced to 70% of the 1973 level. Electric power

Table 10. Potential impact of electricity usage on oil and gas import requirements

	1973	2000		
Electric fraction	26.4	44.5[a]	54.8[a]	65.2[a]
Oil and gas supplies and requirements				
Requirements:				
for electricity	7	5	5	5
for direct use	50	74	60	46
Supply:				
from domestic production	43	43	43	43
from imports	14	36	22	8
Year 2000 imports/year 1973 imports		2.6	1.6	0.6

[a]Includes allowance for conservation and environmental improvement energy costs.

Table 11. Estimates of solar thermal and geothermal electricity generation capacities (MWe)

	1975	1980	1985	2000
Geothermal	500	1 000	10 000	40 000
Solar thermal	0	10	1 000	50 000

plants will be the only substantial means for converting coal to usable energy by the year 2000. Commercial synthetic oil and gas from coal will by then only be making a modest contribution because of the long lead time required for significant penetration into national productive capacity. With the first full-scale demonstrations occurring in the mid-1980s, the contribution of synthetics to the national energy supply will be modest by the year 2000.

Even with the minimum planning target of 7 500 billion kWh/year, the need for imported oil and gas is likely to be 57% greater than 1973 levels. If the national response to the need for conservation is anticipated to be weak, then it would be desirable to implement an intensive electrification programme to utilize coal and uranium and to plan for a target of 10 700 billion kWh/year. This would be the most cautious national policy at the present time.

US energy source planning targets for the year 2000

Only two new energy sources could be commercially significant by the year 2000 – solar and geothermal stations. Except for dry steam geothermal (a very scarce resource), neither of these is sufficiently commercialized to permit a good estimate of their growth. Solar's principal contribution up to the year 2000 will be in the heating of new residential and commercial buildings; the possible result being a reduction in oil and gas demand for such purposes. Solar electricity is very unlikely to be available commercially during this period. Geothermal electricity is uncertain because of engineering and hydrothermal resource issues. However, for the purposes of this analysis, the optimistic projections of the US Energy Research Development Administration (ERDA) are used for estimating the possible contribution of these sources, as shown in Table 11.

In the context of new sources it is important to emphasize the lead time required for a new system to make a significant contribution to a large national energy system. The maximum rate at which any new power generation technology might be integrated into the existing system is projected in Figure 11. In this extreme case it is assumed that there will be successful operation of a pilot plant by 1980 and completion of a large demonstration plant by 1985. Capacity is assumed to grow at 5% per year, with a new plant construction time of eight years. The curve on the left quite optimistically assumes that half of all new power plants ordered after about 1993 employ the new technology. This curve also assumes that even before the first commercial unit begins operation in 1990, over 20% of all plant orders will be this new type.

Even with such rapid introduction, the new option would represent only about 8% of our national electricity production by the year 2000 (right hand curve). Historically, lead times of 30 to 50 years have been required for new energy sources to substitute for or substantially

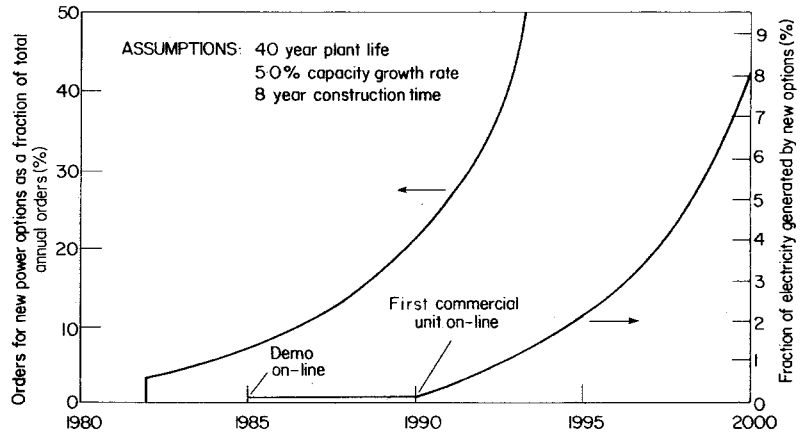

Figure 11. Integration rate of new power option (hypothetical example)

add to, energy supplies. This is the time span usually required from the first demonstration of feasibility, through commercial development, to eventual integration into operating systems on a substantial scale. Such long lead times are characteristic of all major innovations.

US energy source planning targets for the year 2000 are summarized in Table 12. The portion required for electricity generation is also shown in Figure 12.

Even with optimistic assumptions about the contributions of geothermal and solar thermal electric energy, coal and nuclear energy must provide at least 80% of the electricity generated in the year 2000. No foreseeable technology can substantially alter this. Furthermore, the only projection which implies less oil and gas consumption than in 1973 (57.5×10^{15} Btu) is that which assumes accelerated electricity growth. On this assumption oil and gas consumption in the year 2000 will be 50.9×10^{15} Btu.

The estimated mix of electric generating capacities required to meet the minimum planning target of 7 500 billion kWh/year generated in the year 2000 is shown in Table 13.

Any concern with possible overexpansion, as a result of setting too high an achievement target, does not appear to be justified in planning

Table 12. US primary energy source planning targets, actual and projected (10^{15} Btu/year)

Energy source	1960	1973	2000		
			Electricity growth		
Fuels for electricity			Reduced	Historical	Accelerated
Coal	4.3	8.7	26.5[a]	34.3[a]	42.0[a]
Nuclear	—	0.9	26.5[a]	34.3[a]	42.0[a]
Oil and gas	2.2	7.2	5.0	5.0	5.0
Hydroelectric	1.6	2.9	4.0	4.0	4.0
Geothermal and solar thermal	—	—	4.6	4.6	4.6
Sub-total	8.1	19.7	66.6	82.2	97.6
Fuels for direct use					
Coal	6.1	4.7	7.1[b]	5.8[b]	4.5[b]
Oil and gas	30.4	50.3	74.3	60.0	45.9
Solar heating and cooling	—	—	2.0	2.0	2.0
Sub-total	36.5	55.0	83.4	67.8	52.4
Total energy	44.6	74.7	150.0	150.0	150.0
Electricity (% total energy)	18.2	26.4	44.4	54.8	65.1
Electricity generation (10^9 kWh/year)	753	1856	6070	7500	8900

[a]Coal and nuclear contribution assumed to be equal.
[b]Assumed to be 8.6% of direct fossil use ie the same as in 1973.

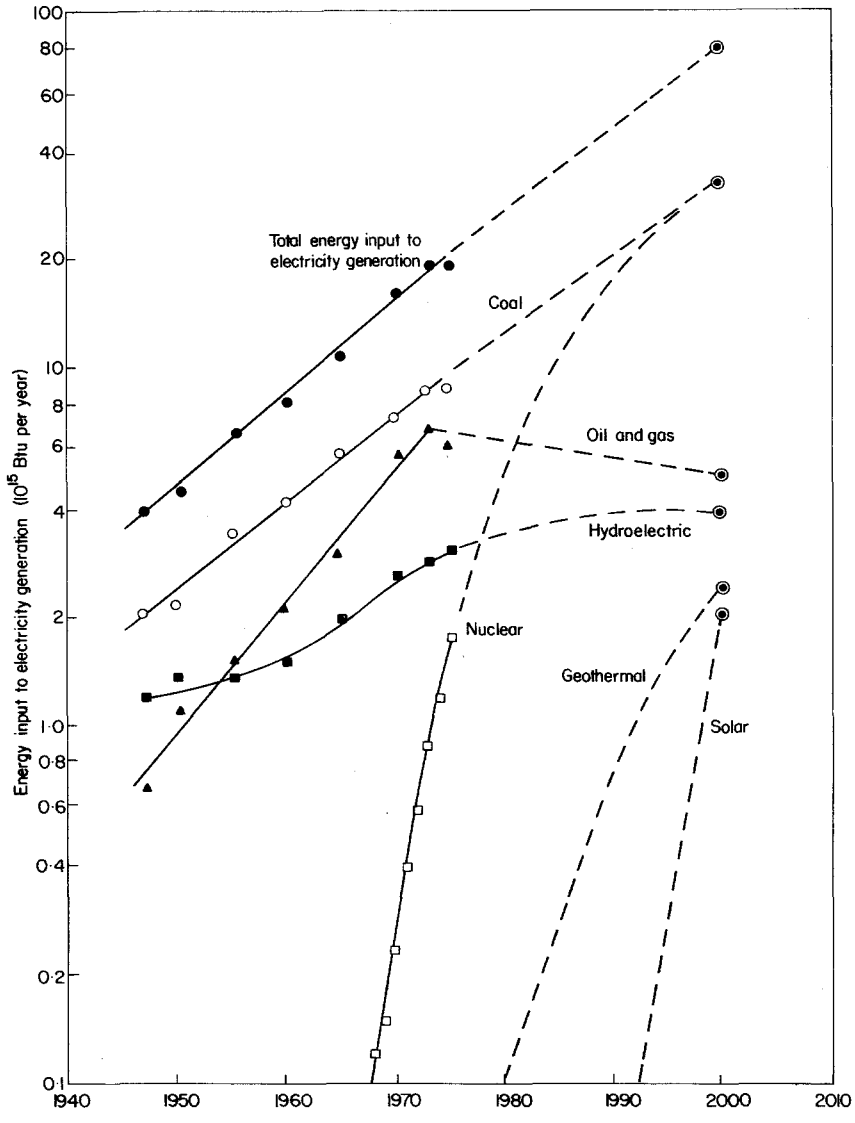

Figure 12. Energy input to electricity generation by utilities in the USA

energy production. The inescapably long time required to accelerate all the components of the US system provides assurance that there will be ample opportunity for continuous assessment, and for rescheduling and retargeting as trend factors become more definite. Even if the practicalities of planning and expansion result in some capital facilities being available before they are needed, such a temporary surplus would certainly be only a small fraction of the total and would, in any case, assure further reduction in consumption of oil and gas.

US economic growth and its impact on society

The value of economic growth in reducing the hardships of everyday life in the USA has been quite evident to most of the population, particularly to those whose lives spanned the period of transition from hardship to affluence. Economic growth has resulted in more employment for all segments of the population, greater real incomes, less poverty, better health, more education, better housing and more

Table 13. US electricity generation capacity for the year 2000, minimum planning target

Energy source	1973 GWe	%	2000 GWe	%
Coal	167	39.5	680	44.0
Nuclear	21	5.0	500	32.4
Oil and gas	172	40.7	200	12.9
Hydroelectric	62	14.7	75	4.9
Geothermal	0.5	0.1	40	2.6
Solar thermal	—	—	50	3.2
Total	422.5	100.0	1545	100.0

recreation time.[9] Most people would agree that a continuation of these patterns of improvement in social welfare is desirable as a national objective.

A quantitative illustration of social progress is provided by considering, hypothetically, the effect of 'no productivity growth' (constant GDP per employee) on past and future levels of employment and personal income.

Employment

Post World War II employment trends in the USA and a possible range for the year 2000 are summarized in Table 14.

Actual figures for the 1948-1973 period show that US employment increased by 26.1 million, that the majority of these jobs were obtained by women, mostly married women as shown in Table 15.

The ability of married women to enter the work force and to find employment is attributed to both the invention of work- and time-saving devices for the home and the creation of full- and part-time jobs. If productivity growth had been frozen at the 1948 level by restricting the use of energy, for example, there would have been nearly 12 million fewer jobs to be filled by women. Extrapolating forward from 1973 to the year 2000, productivity growth should allow the creation of 7.5 million additional jobs for women.

Another valuable benefit from increased productivity throughout the last 85 years has been a continuous decrease in the average time worked daily, weekly, and annually. In 1890, the average US workweek was 54 hours, equivalent to about five and a half ten hour days, although in some sectors a 14 hour day was common. By 1973, the average workweek had decreased to 39 hours or the equivalent of

[9] Executive Office of the President, Office of Management and Budget, *Social Indicators 1973*, US Government Printing Office, Washington, DC, 1973.

Table 14. GDP, employment and energy consumption in the USA

	1948 Actual	1973[a] Assuming no productivity growth from 1948	1973 Actual	2000[b] Assuming no productivity growth from 1973	2000 Continued productivity growth from 1973
GDP/*L* ($ 1958/year/employee)	5 550	5 550	9 940	9 940	17 430
E/*L* (million Btu/year/employee)	582	582	885	885	1 327
Employment (millions)					
Male	41.7	52.0	52.0	64.8	64.8
Female	16.6	20.7	32.4	40.7	48.2
Total	58.3	72.7	84.4	105.5	113.0

[a] Assumes the 1948 ratio of males to females in employment with increases in employment arising from population expansion.

[b] Assumes the 1973 ratio of males to females in employment, with increases in employment arising from population expansion.

Table 15. Female employment (millions)

	1948	1973
Single	9.2	13.5
Married	7.4	18.9
Total	16.6	32.4

almost five eight hour days. The decrease of 15 hours per week is equivalent to an annual increase in leisure time of 78 ten hour working days taken as sick leave, weekends, holidays, and vacation. Continuing the historical trend of productivity increases from 1973 to the year 2000 is expected to reduce the workweek to 36 hours, which is equivalent to a leisure-time increase of more than 18 eight hour working days per year.

Family income and expenditures

Economic growth as measured by GDP per capita means growth of real personal income as described by the following empirical equation that has been derived from data for the USA, starting at 1900:

$$PI_c = 0.919\,\mathrm{GDP}_C - 400$$

where PI_c = personal income per capita in 1975 dollars per year per person and GDP_C = gross domestic product per capita in 1975 dollars per year per person.

Although each of these parameters is one measure of the well-being of US society, personal income per capita is more indicative of the income that can be spent by the public.

From 1948 to 1973 mean real family income in the USA rose an astonishing 111%. This increased real income is the result of higher economic productivity associated primarily with the expanded energy use per employee throughout the economy. However, it is more revealing to examine the changes in personal consumption expenditures and government expenditures for social improvements as shown in Table 16.

Table 16. US family income and expenditures and government expenditures (1948-1973) (1975 dollars)

	1948	1973	Ratio of 1973 figure to 1948 figure
Mean family income	8 250	17 440	2.1
Taxes	820	2 500	3.0
Disposable family income	7 430	14 940	2.0
Personal consumption expenditures and savings			
Housing	1 720	3 860	2.2
Food	2 290	3 050	1.3
Clothing	1 040	1 580	1.5
Transportation	690	1 670	2.4
Medical care	300	1 030	3.4
Recreation	380	880	2.3
Personal business	230	760	3.3
Education	50	220	4.4
Savings	530	1 220	2.3
Other	200	690	3.5
Total	7 430	14 940	
Government expenditures per family			
Social security, welfare and other transfer payments	680	1 830	2.7
Health	80	620	7.8
Education	280	1 140	4.1
Housing	20	140	7.0
Total	1 060	3 730	3.5

Because of economic productivity growth, a family was able to improve its lifestyle over this period by spending considerably more real dollars on the necessities of life, medical care, cultural activities, mobility, recreation, and future security.

Again, looking forward from 1973 to the year 2000, continued historical growth in economic productivity should result in an additional increase of nearly 100% in mean family income, to about $35 000 (1975) per year.

Conclusions

It appears that in the USA increased labour productivity, requiring increased energy input per worker, has resulted in substantial social progress and improved living standards. If continuation of this trend is desirable as a national objective and we wish to avoid energy constraints on social progress, the USA should adopt a primary energy supply target for the year 2000 of *150×10^{15} Btu/year* (growth rate of 2.6% per year); the associated electricity planning target should be *7 500 billion kWh per year* (growth rate of 5.6% per year).

To achieve these targets, energy must be mainly derived from the principal indigenous fuel resources of *coal* and *uranium*, while preserving oil and gas for non-substitutable uses. Since new energy supply options have historically taken 30-50 years to appreciably change the energy mix, we should not count on substantial quantities of energy from solar, geothermal, nuclear fusion, wind, biomass, ocean thermal or other sources in the next quarter century. However, continuous diligent efforts in research, development, engineering and system integration for these future options should be pursued to assure their availability to the generations of the 21st century.